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Feasibility Study on Reuse of Washed Water in Electronic Industry: case study for flexible printed circuit board manufacturing in Thailand

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Abstract

Water reuse for final cleaning process in electronic industry is evaluated. The target factory produces flexible printed circuit boards, which are washed with purified deep-well water as a final process before packaging. Survey of water consumption and its quality was conducted. Feasibility study aims to find the suitable schemes the factory can apply to the real practice when the water consumption rate for final cleaning process increases, with a few conditions that need to be concerned. Material flux analysis and economical evaluation are also performed. It is found that the water needs to be treated before reusing due to the conductivity and LPC that are too high. It is, therefore, suggested that the reused water recharged to both RO unit and ion-exchanger at a suitable ratio. The most attractive alternative in term of both technical and economical aspects is when the recharged ration is 30:70. Raw water consumption can be saved up to 19,760 m^3 per year and the investment can be paid off within 2 years.

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keywords: flexible printed circuit board manufacturing; cleaning process; conductivity; LPC; material flux analysis; economical evaluation

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1. Introduction

The electronics industry is one of Thailand's largest industries in the manufacturing sector which has been continuously expanded. Although the great flood in 2010 caused serious struggles on industrial sectors of the country, the electronic industry has been quickly recovered. It is predicted that the export values of electronic parts and appliances will reach 33,500 million USD at the end of fiscal year 2013, approximately 5% increasing from the previous year [1]. It is also known that the cleanliness of the manufacturing processes and products are very important in the electronic industry, especially those involve in computer hard disks, communication devices, and other advanced electronic appliances. Several steps of cleaning processes, using ultra-pure water, are applied to the manufacturing lines. With increasing production capacity, increasing amount of raw water is required. In this study, the opportunity of water reuse in one of the flexible printed circuit board manufacturers was investigated, focusing on the final cleaning process, or Flip-Chip process shown in Fig. 1. The process diagram shown here is generic to the flexible printed circuit board manufacturers in Thailand. Two types of contaminants are considered. The first type is dissolved solid which dissociates in water. Sources of dissociable components are flux solution in front process and etching solution in etching process [2]. The second part of contaminants is considered suspended solid in water. Usually, it is dust accumulated on product surface and scrap solder. High purity water is required for the final cleaning process, while the main water resource of the factory is from the deep-wells. The raw water is treated by reverse osmosis filtration (RO) followed by ion-exchanger, before being used in the process. Increasing investment in the industry is realized and leads to increasing of production demands. The existing cleaning process consumes approximately 24 m^3 of raw water each day, but the new requirement for the plant expansion will be 80 m^3. Extra amount of raw water must be extracted under strict regulations on deep-well water consumption in Thailand which limits the daily extraction rate.

2. Methodology

2.1. Water characteristics investigation

The sampling points are shown in Fig. 2. Points 1 is sample of treated water by RO unit, point 2 is sample of treated water by ion-exchanger and point 3 is washed water. The samples were taken every 2 hours at each point for 24 hours to obtain the profile of water characters around the cleaning process. Conductivity of water samples is measured by TOA EC METER model CM-14P.

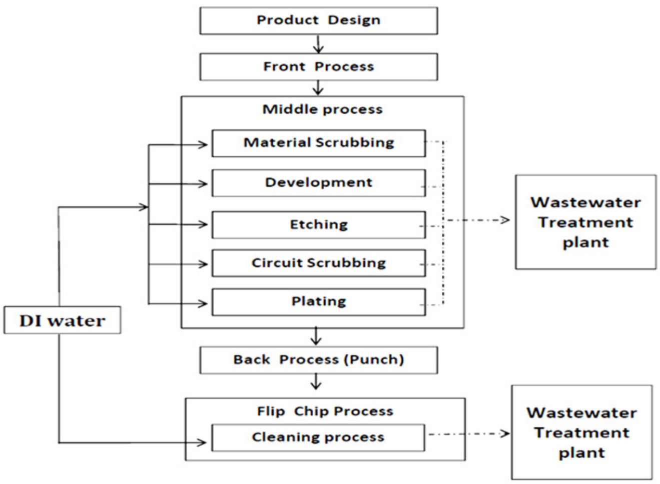

Fig. 1 Process diagram of the factory under this study.

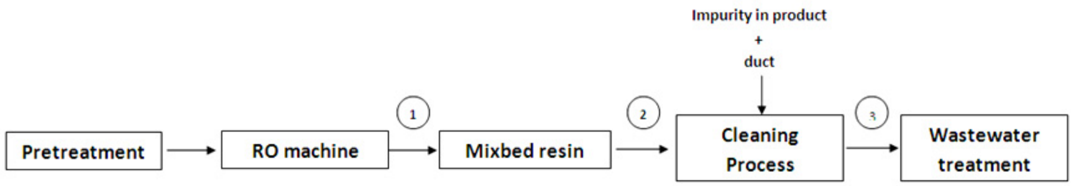

Fig. 2 Sampling points for water characteristics analysis.

Liquid particle counter (LPC) of water samples is measured by LiQuilaz -S05 and PMS model CLS700-T, used in clean room class 100. pH of water samples is measured by TOA model HM-20P with GST – 2739C probe.

2.2. Material Flux Analysis (MFA)

The proposed two inlets of reuse water are demonstrated in Fig. 3. Reuse water A is fed prior to RO unit, and reuse water B is the one fed prior to ion-exchanger (mixed resin). Ratio of A:B is evaluated concerning to its effect on ion-exchanger capacity and the cleanliness of the reuse water. MFA, focused on particles contamination in reuse water, was conducted around the systems of interest to verify the technical feasibility of water reuse. The controlling criteria of the factory under this study are listed as in Table 1.

Table 1. Controlling criteria used under the study.

Parameter	Value
Water consumption rate	80 m^3/d
Conductivity of reuse water	<2 μS/cm
LPC of reuse water	<500 particles/ml
Operating hours	24 hrs/d
Maintenance shut down	Every 14 days

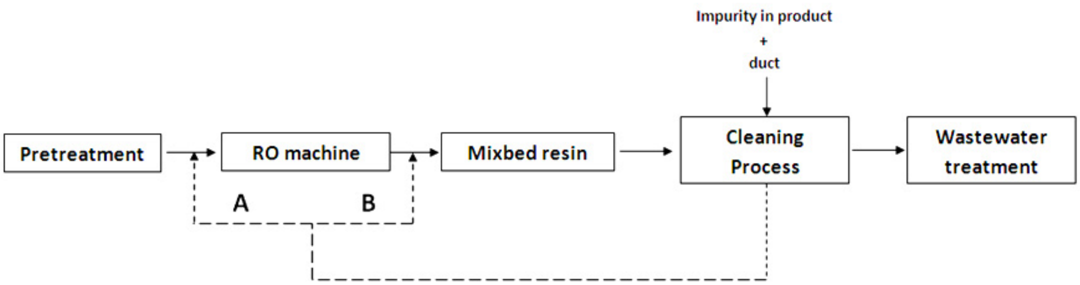

Fig. 3 Proposed reuse water inlets.

2.3. Economical evaluation

Consequence to the study under the methodology 2.2, all conditions applied to the real operation for each alternatives of A:B ratio are considered economically. There are 4 economic parameters evaluated; i.e. net present value (NPV), benefit/cost ratio (B/C), internal rate of return (IRR), and return of investment (ROI). The definitions of these economic parameters are expressed in the following equations.

$$NPV = \sum_{i=0}^{n} \left(\frac{B_t - C_t}{(1+i)^t}\right) \tag{1}$$

$$\frac{B}{C} = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}} \tag{2}$$

$$\sum_{i=0}^{n} \left(\frac{B_t - C_t}{(1+IRR)^t}\right) = 0 \tag{3}$$

$$ROI = \frac{\sum_{i=0}^{n} B_t}{C_0} \tag{4}$$

Where, B_t = profit in year t
C_t = cost of the project in year t
i = discount rate
t = year of the project implementation from 1, 2, 3, …, n
n = lifetime of the project

3. Results and discussion

3.1. Water characteristic

It is obvious that conductivity of washed water is too high to be directly reused, while the LPC is still lower than the allowable concentration. To reuse the washed water, it needs to be treated by ion-exchanger. However, it is recommended that washed water should be partly treated by RO filtration prior to ion-exchanger since the capacity and the lifetime of ion-exchanger is limited. Water characteristics on conductivity, LPC and pH for each sampling point are showed in Fig. 4 to 6, respectively. At sampling point 1, the water has just been treated by RO unit. Its LPC value is the least (averagely 14 particles/mL), while its conductivity is the highest (averagely 21.08 µS/cm). At sampling point 2, water's average conductivity is then reduced drastically to 0.71 µS/cm after passing through ion-exchanger. However, the average particle contamination is slightly increased to 21 particles/ mL. It is possible that the particles contaminants were collected during the flow from point 1 to point 2. At point 3, it is obvious that the LPC is drastically increased to 240 particles/ mL. However, the conductivity of spent water is increased only a little compared to the value before cleaning process. From these results, we understand that the majority of contaminants washed away in the final cleaning process is suspended solid such as dust and dirt which are reflected on the LPC numbers. As for pH, there are insignificant changes along the production hours. The pH of water in the system is mainly affected by the raw water quality. Even the spent water is considered neutral in term of pH measurement.

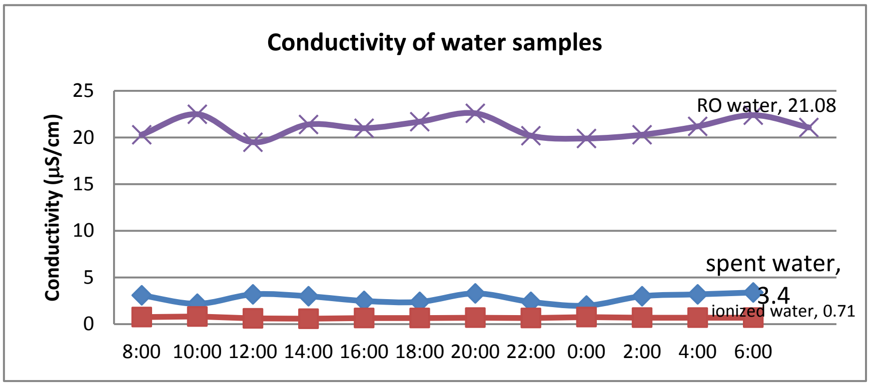

Fig. 4 Conductivity of water at each sampling points.

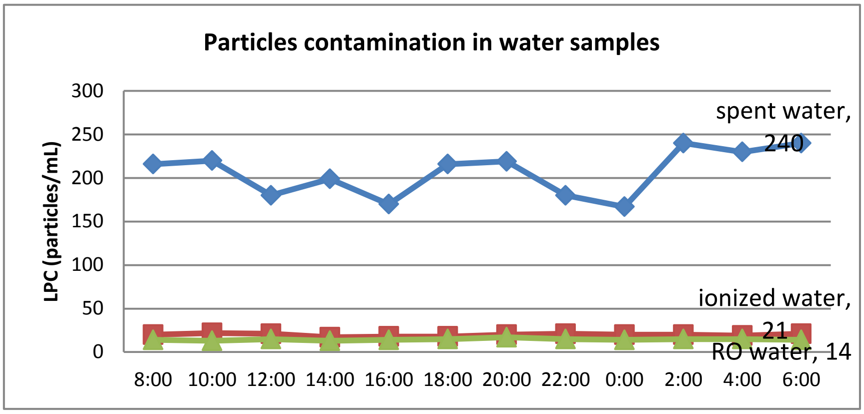

Fig. 5 LPC of water at each sampling points.

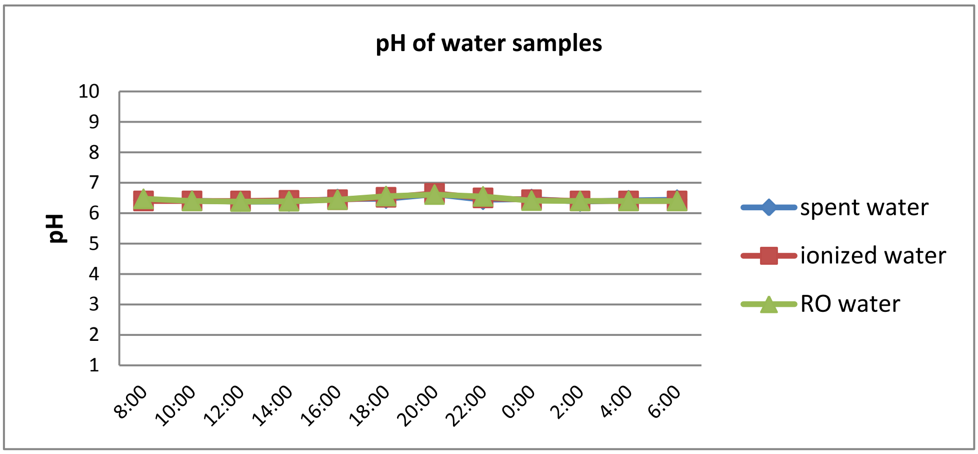

Fig. 6 pH of water at each sampling points.

Regarding the operation criteria of the factory, the water quality that is acceptable for being used in the cleaning process should contain LPC lesser than 500 particles/mL, conductivity lesser than 2 μS/cm, and pH in a range of neutral (pH 6-8). The quality of spent water is still contaminated as the conductivity of point 3 samples exceeds 2 μS/cm. It proves that direct reuse of the spent water from cleaning process is impossible. Deionization of spent water is necessary whether water should be reused. As the capacity of ion-exchanger is limited, splitting the spent water and recharging to the process partly prior to RO unit and partly prior to ion-exchanger seem to be an acceptable alternative.

Even though the LPC of spent water is smaller than the criteria of 500 particles/ mL, but it is prudent to avoid the particles accumulation in the cleaning system and shorten the lifetime of ion-exchanger resins. The overall characteristics of water in the system can be appreciated in Fig. 7.

3.2. Material flux analysis

Material flux analysis around the process was conducted. It is found that the A:B ratio which is satisfied with the factory's operation criteria are ranged from 30:70 to 50:50. When the water is recharged lesser than 30% to RO unit, the ion-exchanger works harder since its charging load is excessive. The whole MFA scheme when A:B ratio of 20:80 is demonstrated in figure 8. We can see that the particles concentration (LPC) in the effluent of ion-exchanger exceeds 500 particles/ mL on the 6th day of operation. It means the operation shut down is taken place every 5 days, contradicts to the goal to shut down every 14 days. Lesser fraction of A will shorten more operation cycle.

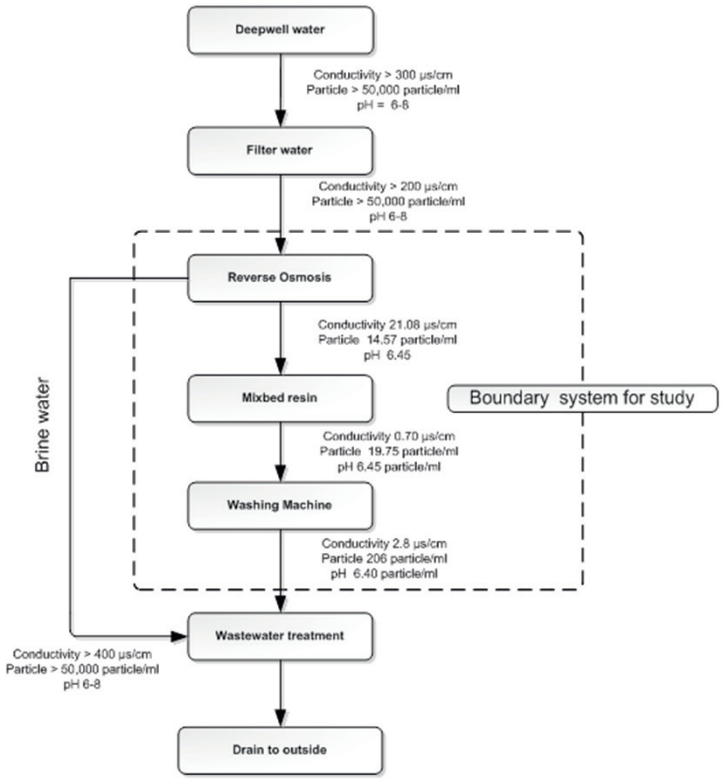

Fig. 7 Overall water characteristics under the study.

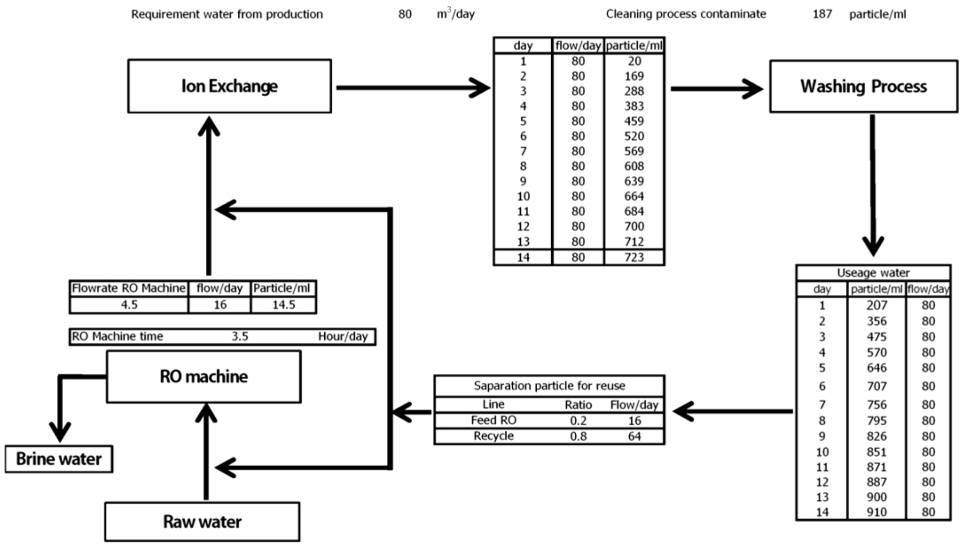

Fig. 8 MFA analysis for 20:80 ratio of reused water.

It is also found that the water consumption rate increases due to the increasing rate of makeup water required. This is caused by the increasing brine water released. The investigation shows that every 21% of water charging to RO unit is drained off as brine [3]. The accumulating water consumption for 1 cycle of operation of 14 days is shown in Table 2. The reuse ratio of 30:70 saves water consumption the most, while the saving rate is decreasing with the increasing of fraction A (in A:B ratio). The consumption rate of raw water can be saved as much as 988 m^3 per cycle or approximately 19,760 m^3 per year. Considering only the raw water cost and regulation, the factory can save up to 800,000 bahts per year without violating the extraction rates limited by the government.

Table 2. Comparison of water consumption with the ration of A:B 30:70, 40:60, and 50:50.

Day	Accumulating raw water consumption without reuse (m^3)	Accumulating raw water consumption with reuse (m^3)					
		30 : 70	saving	40 : 60	saving	50 : 50	saving
1	100	100	0	100	0	100	0
2	200	124	76	132	68	140	60
3	300	148	152	164	136	180	120
4	400	172	228	196	204	220	180
5	500	196	304	228	272	260	240
6	600	220	380	260	340	300	300
7	700	244	456	292	408	340	360
8	800	268	532	324	476	380	420
9	900	292	608	356	544	420	480
10	1000	316	684	388	612	460	540
11	1100	340	760	420	680	500	600
12	1200	364	836	452	748	540	660
13	1300	388	912	484	816	580	720
14	1400	412	988	516	884	620	780

3.3. Economic evaluation

Parameters and conditions applied to the economic evaluation are all listed in Table 3. All of the economical parameters in concerned are shown in Table 4. Although the highest profit can be seen when the water is reused with A:B ratio of 20:80, but it is not technically feasible since the process needs to be shut down for every 5 days as suggested in section 3.2.Therefore, the best alternative of reuse water ratio is when A:B ratio is 30:70. The NPV is 2,218,084.67 Baht, B/C is 1.52, IRR is 48.12 %, and ROI is 49.09%. Since the new water purification process is required for the alternative without water reuse, all parameters are the lowest compared to all cases of water reuse.

Table 3. Conditions applied to the economic evaluation.

Details	Conditions
1. Lifetime of the factory	10 years
2. Investment costs	
2.1 Raw water extraction system for factory expansion	300,000 bahts
2.2 Ionized water purification unit with capacity of 56 m3 (without reuse)	2,000,000 bahts
2.3 Ionized water purification unit with capacity of 56 m3 (with reuse)	500,000 bahts
2.4 Storage installation (without reuse)	20,000 bahts
2.5 Storage installation (with reuse)	60,000 baht
2.6 Water distribution system (without reuse)	50,000 bahts
2.7 Water distribution system (with reuse)	500,000 bahts
3. Operating costs	
3.1 Raw water extraction fee	2.625 baht/m^3
3.2 Electricity fee	4 baht/kWh
3.3 Maintenance cost (without reuse)	48,000 bahts
3.4 Maintenance cost (with reuse)	72,000 bahts
4. Discounted rate	10%
5.Raw water procurement (without reuse)	40 Baht/m^3
6. operating hours	330 day/year

Table 4. Comparison of the economic parameters for all alternatives.

	Alternatives				
Parameters	No water reuse	Water reuse 20:80	Water reuse 30:70	Water reuse 40:60	Water reuse 50:50
NPV (Baht)	100,367.83	2,319,410.69	2,218,084.67	2,036,386.37	1,827,198.03
B/C ratio	0.98	1.56	1.52	1.46	1.39
IRR	9.02	49.69	48.12	45.29	42.01
ROI	15.55	49.69	49.09	46.40	43.31

4. Conclusion

The study shows that the water reuse for the final cleaning process of the flexible printed circuit board manufacturers is feasible, technically and economically. Investigation of water quality shows that conductivity of spent water is higher than allowable threshold so that the deionization of water is necessary, using ion-exchanger. With an existing process, water consumption at a rate of 80 m^3 per day can be accomplished without extracting more raw water. We can reduce the load of the ion-exchangers by splitting reuse water, recharging stream to RO units, and the best ratio is 30:70. Regarding the economic evaluation, every alternative of water reuse looks promising. Nevertheless, the higher rate of reuse back to RO unit leads to lesser profit shown through all parameters.

The concept of this work can be generally applied to any flexible printed circuit board manufacturers in Thailand, since the main difficulty they are facing at the moment is to increase the production capacity with the excessive rate of ground water consumption. Reuse of washed water does not only help to save the operating cost, but also promote the sustainability of the groundwater resource and local environment.

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